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ESTIMATING THE MAXIMUM SUSTAINABLE YIELD OF SOUTH PACIFIC ALBACORE, 1971-1985[1]

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ABSTRACT

Based on the annual reports of catch statistics of tuna longline fisheries of Taiwan, Japan and Korea, annual catch of albacore of the South Pacific Ocean in 1971-1985 was estimated. The overall effective fishing effort of tuna longliners has been computed by Honma's method. A generalized production model

$$dP/P\,dt = r(1-(P/K)^m) - F$$

was used to assess albacore stock after a 5-year smoothing the effective fishing effort. The results of fitting to the production model for different combinations of $m=1$-5 and the number of year class, $k=1$-5, contributing to the longline fisheries are compared. The correlation coefficient of CPUE as a linear function of the effective fishing effort was used to determine the goodness of fitting to the production model. The results reveal that fitting is better for higher k-values with given m. In the case of $k=5$ and $m=1$-3, the optimal effective fishing effort, f_{opt} and the maximum sustainable yield, C_{msy}, are computed as follows.

$m=1$: $f_{opt}=207.31$ million hooks, $C_{msy}=31222$ metric tons.
$m=2$: $f_{opt}=222.14$ million hooks, $C_{msy}=32033$ metric tons.
$m=3$: $f_{opt}=231.58$ million hooks, $C_{msy}=33005$ metric tons.

INTRODUCTION

Albacore (*Thunnus alalunga*) is an important tuna species in the South Pacific Ocean. Most of them are exploited by tuna longline fisheries of Taiwan, Korea and Japan. These longline vessels are mainly based at American Samoa and other foreign ports. Only a few quantities of South Pacific albacore are caught by surface fisheries in Chile and New Zealand. The U.S. South Pacific albacore fishery began in 1986 with two commercial troll vessels working along the Subtropical Convergence Zone (Laurs *et al.* 1987).

Although, many papers for the South Pacific albacore were published (Honma and Kamimura 1957; Kurogane and Hiyama 1958; Otsu and Hansen 1962; Koto 1966; Otsu 1966; Koto and Hisada 1967; Otsu and Sumida 1968; Slack 1969; Yoshida 1971; Otsu and Yoshida 1971; Slack 1972; Robert 1974; Yoshida 1975; Skillman 1978, etc), only a few papers were tried to estimate the maximum sustainable yield (Skillman 1975; Wetherall *et al.* 1979; Wetherall and Yong 1984, 1987). Wang (1988) published a paper to discuss the seasonal changes of the distribution of South Pacific albacore based on the catch statistics of Taiwan's tuna longline fishery, 1971-1985.

In this paper, we try to estimate the maximum sustainable yield of tuna longliners of South Pacific albacore by generalized production model based on

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catch statistics of tuna longline fisheries of Taiwan, Korea and Japan. We also try to give a better estimation of annual catch statistics of South Pacific albacore longliners.

MATERIALS AND METHODS

In this paper, the South Pacific Ocean means the area of tuna longline fishing grounds defined in "Annual Catch Statistics of Taiwanese Tuna Longline Fishery" (NTUIO 1985).

Catch statistics of Taiwan's tuna longline fishery in 1971-1985 are used in this study. All of these data are provided by Tuna Research Center (NTUIO 1971-1985). In 1971, the total catch and hooks are raised by the ratio of total used sets and sampling sets. In 1972 to 1976, catch statistics are raised by those ratios estimated by hooks used. Before 1977, no raising rate of each 5-degree square was available. Here, we assume that all of the 5-degree squares have the same coverage rate as stated above and use it to raise the catch of each small area. From 1977 on, coverage rates computed by hooks used are available for each 5-degree square. These ratios are also used to raise the catch statistics of each 5-degree square, and then, summarized them to get the total catch of weight, number of individuals and hooks used: The coverage rates of overall fishing grounds are shown in Table 1.

Before 1976, catch statistic data of shark, skipjack and other fishes haven't been included in the annual reports. In 1976-1977, only catches in number of these three species were collected. From 1978 on, catches in both weight and number of these three species were published in annual reports (NTUIO 1971-1985). In this paper, raising procedures also include the estimations of these three species. Total catches are estimated by Tuna Research Center (NTUIO, unpublished), Catch statistics of Taiwan's tuna longline fishery in 1971-1985 are shown in Table 1. Here, the percentages of albacore to the total catch are computed as catch in number of individuals. The effective fishing efforts are estimated by Honma's Method (1974). Catches per unit of fishing effort are represented by both catch in kilogram per 100 hooks and number of fishes per 100 hooks.

Catch statistic data of the South Pacific Ocean of Japan's tuna longline fishery are adopted from "Annual Report of Effort and Catch Statistics by Area on Japanese Tuna Longline Fishery" (Fisheries Agency of Japan, 1971-1985). In these annual reports, only the data of catch in number by month and by 5-degree squares are available. Some differences exist in the definition of South Pacific fishing grounds between Taiwanese and Japanese annual reports of longline fisheries. Here, the estimation of catch statistics of South Pacific albacore is adjusted to the same definition of fishing grounds as those given in Taiwan's longliners (NTUIO 1985). Average weight per individual is recalculated from the data of Wetherall and Yong (1987, in Table 1). When the average weight is not available, it is estimated by 5-year smoothing the average weight. Annual catches in weight are estimated by multipling the average weight by the number summarized from the annual reports. Because of the difference of data sources, estimating method and the definition of fishing ground of South Pacific albacore, the values of annual catch given in this paper are different from those estimated by Wetherall and Yong (1987). The differences may be concluded as follows. (1) The definition of South Pacific fishing grounds. In Japan's annual reports, South Pacific fishing ground means those areas west of 130°W and south of 5°N. In

Taiwan, we mean those areas west of 80°W and south of equator. (2) In this paper, catches in weight are estimated by a product of number of fish multiplied by average weight per individual. Here, average weights per individual are estimated by moving average of last five years for which data are unavailable. The results are given in Table 2.

Only eight years (1975-1982) of Korean catch statistic data of longliners published by month and by 5-degree square are available in this paper (Fisheries Research & Development Agency of Korea 1980, 1981, 1985, 1986). All of calculations of Korea's catch statistics of 1975-1982 in this analysis are based on these eight annual reports. Catches in weight in 1971-1974 are adopted from FAO (1980, Table 11). In 1983-1985, only catches in weight of all of the Pacific Ocean are available. First, we estimate the percentage of catch of South Pacific albacore in 1980-1982 to the whole ocean, and then estimate the percentage of South Pacific albacore in 1983-1985 by smoothing the 3-year average. Average weight per individual was also estimated by the same method given above. Hence, catches in number can be estimated by the rates of catch in weight/average weight per individual in 1983-1985. The values estimated in this paper are close to those shown by Wetherall and Young (1987). In 1975-1982, catches in weight and in number are adopted or computed from the annual reports. Coverage rate is used to raise the annual catch. The values shown in this paper and in Wetherall and Yong's (1987) reveal significant difference due to different data sources and estimating methods. The effective fishing efforts in 1975-1982 are also estimated by Honma's method based on annual reports. For the remainding years, we firstly estimate the CPUE by moving the average of recent five years, then the nominal fishing efforts can be computed by the rate of number/CPUE. Finally, effective fishing effort can be estimated by multipling the nominal fishing effort by the ratio of effective fishing effort/nominal fishing effort after 5-year smoothing the ratios.

As stated above, the estimations used in this paper are very crude; the reasons are large differences in the seasonal changes of fishing grounds, distribution of fishing effort and the target species among these three longline countries. We think it is better than those estimated directly from the ratio of annual catch to the other country or those based on the data collected from the longliners operated out of American Samoa. Over 90% of South Pacific albacore are exploited by longliners of these three countries; here, the analysis in this paper ignores catches of other fisheries.

Next, the maximum sustainable yield of South Pacific albacore stock will be estimated by a generalized production model based on overall annual catches of tuna longliners computed as above.

The surplus production model as given in the following is used to estimate the maximum sustainable yield.

$$\begin{aligned} dP/Pdt &= r(1-(P/K)^m)-F \\ &= r(1-(P/K)^m)-qf \end{aligned}$$

In this paper, f is taken as the weighted mean of fishing effort and given as follows.

$$\bar{f}_t = (kf_t+(k-1)f_{t-1}+(k-2)f_{t-2}+\cdots+f_{t-k+1})/(k+(k-1)+(k-2)+\cdots+1)$$

where, P=population size,
t=year,

r=intrinsic growth rate,
K=carrying capacity,
F=fishing mortality coefficient,
f=effective fishing effort in hooks,
m=shape parameter,
q=catchability,
k=number of year class contributing significantly to the longline fishery (Fox 1975).

RESULTS

As shown in Table 1, it reveals that albacore is the target species of Taiwanese tuna longline fishery, especially in recent years. The percentage of albacore in the total catch increased year by year, and it was over 90% after 1983. No significant decreasing trend in both catch per unit of fishing effort (CPUE) of number and weight can be found through a long time exploitation. Both remain at a rather high level. But, the average weight per individual reveals a decreasing trend after 1976. The effective fishing efforts had peaks in 1973, 1977 and 1980, and then decreased year by year after 1980. In 1985, only 13201 thousand hooks were used to exploit the South Pacific albacore. The peaks of catch occur in 1973, 1977 and 1980. The fluctuation seems very large, especially during 1979–1981. In 1979 and 1981, total catches are just over 12 thousand metric tons, but it is over 27 thousand metric tons in 1980. After 1980, a clear decreasing trend can be found in Table 1. In 1985, only 6095 metric tons of albacore are obtained by Taiwanese tuna longliners.

As given in Table 2, albacore occupied a very low percentage, lower than 20%, in catch statistics of Japanese tuna longline fishery. CPUE are lower than those of Taiwan. They are lower than 10% of Taiwanese CPUE. Although the effective fishing effort is nearly 3.5 times of those of Taiwanese tuna longliners, the average annual catch of South Pacific albacore reaches one-fifth of that caught by Taiwanese longliners only. But, a comparatively stable level of catch of Japanese longliners can be found in Table 2. All of them are lower than six thousand metric tons. Effective fishing efforts of longliners show an increasing trend before 1980 and a decreasing trend after 1982. As shown in Table 2, peak of catches in weight is 5505 mt in 1981. The lowest is 1047 mt in 1975. The average weight per individual is lower than that of Taiwanese longliners, especially before 1975.

Table 3 shows the catch statistics of Korean tuna longliners. CPUE are lower than those of Taiwan, but higher than Japan. The percentage of albacore of the total catch of longliners are also lower than those of Taiwan and higher than those of Japan. In 1982, the average CPUE in number is 0.971 per 100 hooks and 15.67 kg per 100 hooks in weight. Both are lower than Taiwan (3.006 and 45.14, respectively), and higher than Japan (0.815 and 2.60, respectively). The average percentage of albacore of the totol catch is 39.79%. It is lower than 82.0% of Taiwan and higher than 11.41% of Japan. Attention must be paid to the violent fluctuation of catches of Korea. The total catch reached seventeen thousand metric tons in 1973, and heavily decreased to a rather low level in 1975 with ninteen hundred metric tons only. During 1975–1982 for which actual catch data are available from annual reports, it can be found quickly increasing trends in 1975–1976, 1977–1978, and 1980–1981; and heavily decreasing trends in 1976–1977, and 1978–1980.

Table 1. Catch statistics of Taiwan's tuna longline fishery in South Pacific albacore fishing ground

Year	Catch in		Fishing effort $\times$ 1000H		CPUE N/100H		CPUE kg/100H		Percentage	Average	Coverage
	Weight (mt)	Number	Nominal	Effective	Nominal	Effective	Nominal	Effective	Alb./Total %	wt in kg	rate %
1971	19677	1232172	35733	43023	3.448	2.864	55.067	45.736	66.64	15.969	32.77
1972	21965	1356806	40134	41378	3.381	3.279	54.729	53.084	69.65	16.189	24.74
1973	26795	1628518	54211	52585	3.004	3.097	49.427	50.956	73.66	16.454	16.80
1974	19009	1321657	50456	48740	2.619	2.712	37.674	39.001	79.49	14.383	10.92
1975	13343	885335	35452	32368	2.497	2.735	37.637	41.223	78.76	15.071	16.27
1976	18129	1122298	36927	29984	3.039	3.743	49.094	60.462	80.40	16.153	10.41
1977	24620	1693870	46214	45567	3.665	3.717	53.274	54.030	86.91	14.535	26.04
1978	18732	1348656	33418	36927	4.036	3.652	56.054	50.727	86.52	13.889	47.54
1979	12376	828903	28945	32939	2.864	2.516	42.757	37.572	76.79	14.931	68.71
1980	27007	1888928	66288	88615	2.835	2.132	40.534	30.477	82.25	14.298	53.33
1981	12041	852967	36496	43467	2.337	1.962	32.993	27.701	86.04	14.117	83.02
1982	10157	691802	26011	29575	2.660	2.339	39.049	34.343	89.57	14.682	78.17
1983	7822	551334	17175	15183	3.210	3.631	45.543	51.518	91.86	14.187	81.53
1984	6771	463664	19779	18118	2.344	2.559	34.233	37.372	90.62	14.603	69.58
1985	6095	418864	14210	13201	2.948	3.173	42.892	46.171	90.90	14.551	67.93
Mean	16303	1085718	36119	38111	3.006	2.849	45.135	42.776	82.00	15.015	45.85

Table 2. Catch statistics of Japan's tuna longline fishery in South Pacific albacore fishing ground

Year	Catch in		Fishing effort ×1000H		CPUE N/100H		CPUE kg/100H		Percentage	Average	Coverage
	Weight (mt)	Number	Nominal	Effective	Nominal	Effective	Nominal	Effective	Alb./Total %	wt in kg	rate %
1971	4320	337526	81089	73286	0.416	0.461	5.327	5.895	20.99	12.799	56.61
1972	2743	219392	79884	78319	0.275	0.280	3.434	3.502	13.67	12.503	53.32
1973	2577	217953	92258	93265	0.236	0.234	2.793	2.763	5.81	11.824	55.08
1974	1836	164851	84242	99056	0.196	0.166	2.179	1.853	13.35	11.137	58.40
1975	1047	88024	79615	84157	0.111	0.105	1.315	1.244	6.83	11.894	62.15
1976	2474	145233	112823	141871	0.129	0.102	2.193	1.744	6.64	17.035	81.64
1977	2267	170682	120594	121725	0.142	0.140	1.880	1.862	8.80	13.282	85.12
1978	3132	192460	117135	118244	0.164	0.163	2.674	2.649	9.82	16.274	75.12
1979	2542	182579	127323	133176	0.143	0.137	1.996	1.909	8.82	13.923	75.45
1980	2679	184985	170933	199656	0.108	0.093	1.567	1.342	6.80	14.482	79.53
1981	5505	367020	175645	165698	0.209	0.221	3.134	3.322	13.22	14.999	89.46
1982	5325	364920	157468	210189	0.232	0.174	3.382	2.533	15.07	14.592	89.87
1983	5745	386715	137187	143353	0.282	0.270	4.188	4.008	15.70	14.856	87.09
1984	4236	290714	131645	155648	0.221	0.187	3.218	2.722	14.32	14.571	93.48
1985	4203	285958	126872	127708	0.225	0.224	3.313	3.291	11.25	14.698	90.79
Mean	3375	239934	119648	129690	0.201	0.185	2.821	2.603	11.41	14.068	75.54

Table 3. Catch statistics of Korea's tuna longline fishery in South Pacific albacore fishing ground

Year	Catch in Weight (mt)	Catch in Number	Fishing effort ×1000H Nominal	Fishing effort ×1000H Effective	CPUE N/100H Nominal	CPUE N/100H Effective	CPUE kg/100H Nominal	CPUE kg/100H Effective	Percentage Alb./Total %	Average wt in kg	Coverage rate %
1971	14482	778602	130638	93808	0.596	0.830	11.086	15.438		18.600	
1972	14439	776290	128952	93529	0.602	0.830	11.197	15.438		18.600	
1973	17452	948478	151272	111586	0.627	0.850	11.537	15.640		18.400	
1974	12194	677444	94352	71235	0.718	0.951	12.924	17.118		18.000	
1975	1900	95021	40880	18047	0.232	0.527	4.648	10.528	15.75	19.996	9.6
1976	11599	623596	69072	62837	0.903	0.992	16.793	18.459	38.66	18.600	17.8
1977	8568	599176	66036	53176	0.907	1.127	12.975	16.113	38.43	14.300	44.9
1978	11050	731808	41646	33743	1.757	2.169	26.533	32.748	50.67	15.100	64.7
1979	8678	598487	57286	47798	1.045	1.252	15.149	18.156	41.38	14.500	35.7
1980	5241	302955	82890	69581	0.365	0.435	6.323	7.532	17.08	17.300	59.9
1981	14914	994260	100000	113607	0.994	0.875	14.914	13.128	59.46	15.000	33.1
1982	12648	951003	79516	71971	1.196	1.321	15.906	17.574	56.88	13.300	34.9
1983	6669	459931	43431	45856	1.059	1.003	15.355	14.543		14.500	
1984	5730	403521	36818	39717	1.096	1.016	15.563	14.427		14.200	
1985	10267	723028	65730	68275	1.100	1.059	15.620	15.038		14.200	
Mean	10389	644240	79235	66318	0.813	0.971	13.111	15.665	39.79	16.126	37.6

Table 4. Catch statistics of overall tuna longline fishery in South Pacific albacore fishing ground

Year	Catch in		Fishing effort ×1000H		CPUE N/100H		CPUE kg/100H		Average
	Weight (mt)	Number	Nominal	Effective	Nominal	Effective	Nominal	Effective	wt in kg
1971	38479	2348300	247460	210117	0.94896	1.11762	15.54958	18.31313	16.38590
1972	39147	2352488	248970	213226	0.94489	1.10328	15.72358	18.35939	16.64068
1973	46824	2794949	297741	257436	0.93872	1.08569	15.72642	18.18860	16.75303
1974	33039	2163952	229050	219031	0.94475	0.98797	14.42436	15.08417	15.26790
1975	16290	1068380	155947	134572	0.68509	0.79391	10.44586	12.10504	15.24738
1976	32202	1891127	219452	234692	0.86175	0.80579	14.67382	13.72096	17.02794
1977	35455	2463728	232844	220468	1.05810	1.11750	15.22693	16.08170	14.39079
1978	32914	2272924	192199	197554	1.18259	1.15053	17.12496	16.66076	14.48091
1979	23596	1609969	213554	213913	0.75389	0.75263	11.04920	11.03065	14.65618
1980	34927	2376868	320451	357852	0.74173	0.66420	10.89933	9.76018	14.69455
1981	32460	2214247	312141	322772	0.70937	0.68601	10.39915	10.05663	14.65961
1982	28130	2007725	262995	311735	0.76341	0.64405	10.69602	9.02369	14.01088
1983	20236	1397980	197793	204392	0.70679	0.68397	10.23090	9.90058	14.47517
1984	16737	1157899	188242	213483	0.61511	0.54238	8.89121	7.83997	14.45463
1985	20565	1427850	206812	209184	0.69041	0.68258	9.94381	9.83106	14.40277
Mean	30067	1969892	235043	234695	0.83810	0.83934	12.79199	12.81097	15.26313

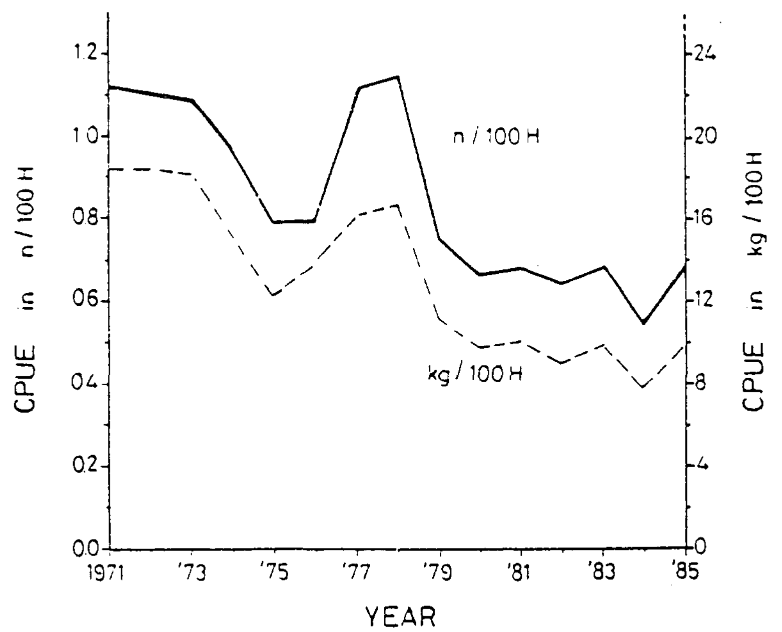

Fig. 1. Variation of abundance index of South Pacific albacore exploited by tuna longliners.

All of the catch statistics of tuna longline fisheries of Taiwan, Korea and Japan are summarized and given in Table 4. As shown in Fig. 1, both of catch per unit of fishing effort of weight and number reveal a strictly decreasing trend after 1973. During 1975-1985, they maintain at a horizontal level with a slightly decreasing trend except 1977-1978. As shown in Table 4, peak of average weight per individual occured in 1976. Peak of longline catch occured in 1973 with a total catch of 46824 metric tons of South Pacific albacore. In 1975 and 1984, just over sixteen thousand metric tons of albacore are exploited. The average CPUE is 0.838 in number per 100 hooks and 12.811 in kilogram per 100 hooks.

No significant correlation coefficient between CPUE and effort can be found in both of number (Fig. 2) and of weight (Fig. 3). Now, the problem is how to fit CPUE as a function of fishing effort, that is to determine the values of k and m if we try to use the generalized production model to assess the maximum sustainable yield.

As pointed out by Gulland (1983), it is difficult to determine the degree to which past levels of fishing effort affect the current stock abundance. The most important question is whether the level of recruitment of young fish to the fishery is significantly influenced by the abundance of adults. If enough is known about the population and its structure and dynamics and if it is confident that changes in adult stock affect recruitment, then there will be enough information available for the more complex analytical methods (Ricker 1954; Beverton and Holt 1957, among others) to asses the maximum sustainable yield.

If recruitment stays constant under increasingly heavy fishing, the average size of fish will fall. Conversely, if the average size of fish remains the same while the abundance, or CPUE, falls, there is some evidence that recruitment is affected. If recruitment is not affected, then fishing in one year can affect the stock only so long as some fish exposed to fishing in that year remain in the exploited stock. This potential life span in the fishery, say k years, provides an upper limit to the length of period that needs to be considered. Gulland (1983) said that a reasonable approximation to the mean life span in the fishery might be taken as one-half to one-third of the potential life span.

As stated above, the target species of tuna longline fishery are very different in Taiwanese, Korean and Japanese longliners. And, as pointed out by Wang

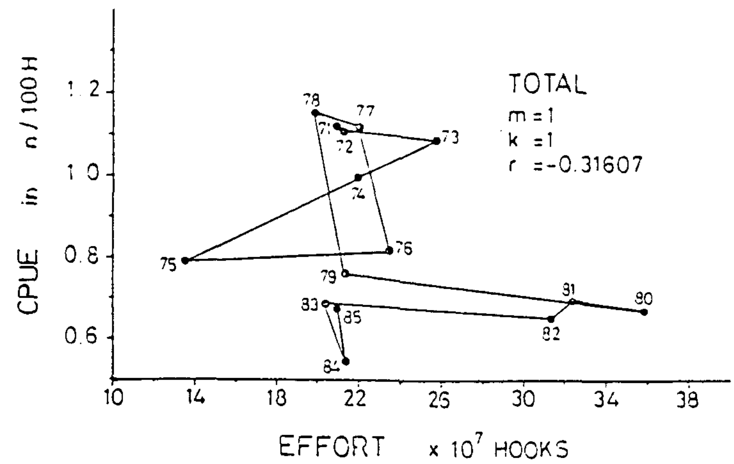

Fig. 2. Relationship between the CPUE in number of fish per 100 hooks used and the effective fishing effort.

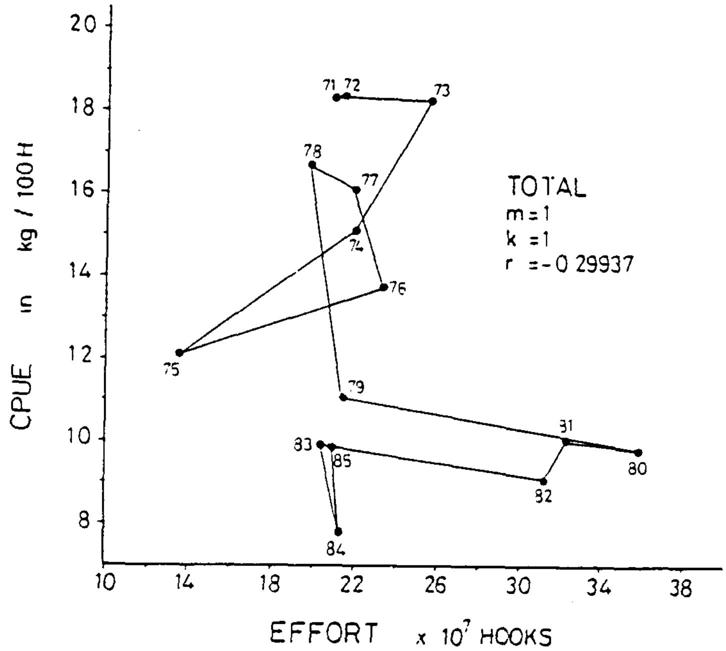

Fig. 3. Relationship between the CPUE in kilogram per 100 hooks used and the effective fishing effort.

Table 5. Fitting CPUE (in number) as a linear function of effective fishing effort with $U^m = a + bf$ for various combination of m- and k-values

U=catch in number/100 hooks,
f=effective fishing effort in 100 million hooks
r=correlation coefficient,
a=intercept,
b=regression coefficient.

		$k=1$	$k=2$	$k=3$	$k=4$	$k=5$
$m=1$	r	−0.33383	−0.36039	−0.45732	−0.56879*	−0.63619*
	b	−1.28575	−1.62978	−2.36576	−3.32544	−4.12042
	a	1.15907	1.23964	1.41195	1.63723	1.82262
$m=2$	r	−0.32757	−0.35258	−0.44436	−0.55371*	−0.61596*
	b	−2.24502	−2.83732	−4.09047	−5.76064	−7.09902
	a	1.30680	1.44553	1.73892	2.13097	2.44305
$m=3$	r	−0.31967	−0.34257	−0.42927	−0.53677*	−0.59497*
	b	−3.02062	−3.80073	−5.44801	−7.69917	−9.45410
	a	1.45723	1.63995	2.02561	2.55404	2.96321
$m=4$	r	−0.31174	−0.3323	−0.41397	−0.51989*	−0.57503*
	b	−3.71388	−4.64729	−6.62416	−9.40186	−11.52014
	a	1.62211	1.84073	2.30356	2.95557	3.44943
$m=5$	r	−0.30466	−0.32264	−0.39956	−0.50408	−0.55692*
	b	−4.39814	−5.46903	−7.74740	−11.04658	−13.52031
	a	1.81138	2.06221	2.59562	3.37002	3.94674

(1988), main fishing grounds and fishing seasons are different in tuna longline fishery of Taiwan, Korea and Japan. It is difficult to determine the ratio of mean life span of the potential life span of South Pacific albacore tuna longline fishery.

Here, we assume that both of the values of m and k vary from 1 to 5, and try to find a best correlation coefficient of CPUE as a linear function of fishing effort to advance the fitting procedures. The results are shown in Table 5 for CPUE in number per 100 hooks. For the same k-values, greater values of m imply smaller values of correlation coefficient. Conversely, the values of correlation coefficient increase gradually when k increases for the same level of m-values. For the case of $k=5$, that is if weighted mean of fishing effort is calculated by five year classes, it seems to fit better. For the case of CPUE in weight, it seems to have the same trends (Table 6). In the case of $k=5$, the correlation coefficient of $m=1$ is -0.64566^{**} (** means 1% significant level). For $m=2$, it is -0.61237^{*} (*means 5% significant level). For $m=3$, it is -0.57774^{*}.

Assuming that $k=5$, and $m=1$, $m=2$, and $m=3$, and fitting to the generalized production model, the maximum sustainable yield and optimal fishing effort of tuna longline fishery of South Pacific albacore can be estimated. The results are shown in Fig. 4. For the case of $m=1$, that is fitting by logistic curve, the

Table 6. Fitting CPUE (in weight) as a linear function of effective fishing effort with $U^m=a+bf$ for various combinations of m- and k-values

$m=1$ —> U=catch in kilogram/100 hooks,
f=effective fishing effort in 100 million hooks,
$m=2$-5 —> U=catch in kilogram/1000 hooks,
f=effective fishing effort in 100 million hooks,
r=correlation coefficient,
a=intercept,
b=regression coefficient.

		$k=1$	$k=2$	$k=3$	$k=4$	$k=5$
$m=1$	r	−0.34113	−0.37675	−0.47770	−0.58122*	−0.64566**
	b	−21.01921	−29.59984	−42.93239	−59.03590	−72.65138
	a	18.03557	20.04507	23.16648	26.94726	30.12193
$m=2$	r	−0.29673	−0.35908	−0.45389	−0.55321*	−0.61237*
	b	−5.39430	−7.66466	−11.08269	−15.26625	−18.72059
	a	3.11851	3.65020	4.45043	5.43264	6.23801
$m=3$	r	−0.27723	−0.33857	−0.42758	−0.52279*	−0.57774*
	b	−10.70252	−15.34710	−22.17144	−30.63695	−37.50712
	a	5.30636	6.39406	7.99177	9.97924	11.58049
$m=4$	r	−0.25787	−0.31793	−0.40165	−0.49291	−0.54457*
	b	−19.46806	−28.18275	−40.72729	−56.48836	−69.13696
	a	9.00260	11.04346	13.98038	17.68054	20.62941
$m=5$	r	−0.24000	−0.29882	−0.37778	−0.46533	−0.51443*
	b	−34.21786	−50.02471	−72.34412	−100.71082	−123.34141
	a	15.32813	19.02985	24.25526	30.91462	36.19074

maximum sustainable yield is $C_{msy}=31222$ metric tons with an optimal effective fishing effort $f_{opt}=207.31$ million hooks. For the other two cases, we have $C_{msy}=32033$ metric tons, $f_{opt}=222.14$ million hooks for $m=2$ and $C_{msy}=33005$ metric tons, $f_{opt}=231.58$ million hooks for $m=3$. As shown in Fig. 4, this is a parabola for $m=1$, and for larger m-values, the curve is skewed to the right hand. Only those hooks used in 1975 and in 1980-1982 are separated far away from the level of optimal effective fishing effort. In the recent three years 1983-1985, the nominal hooks used were very close to those of the level of optimal effective fishing effort.

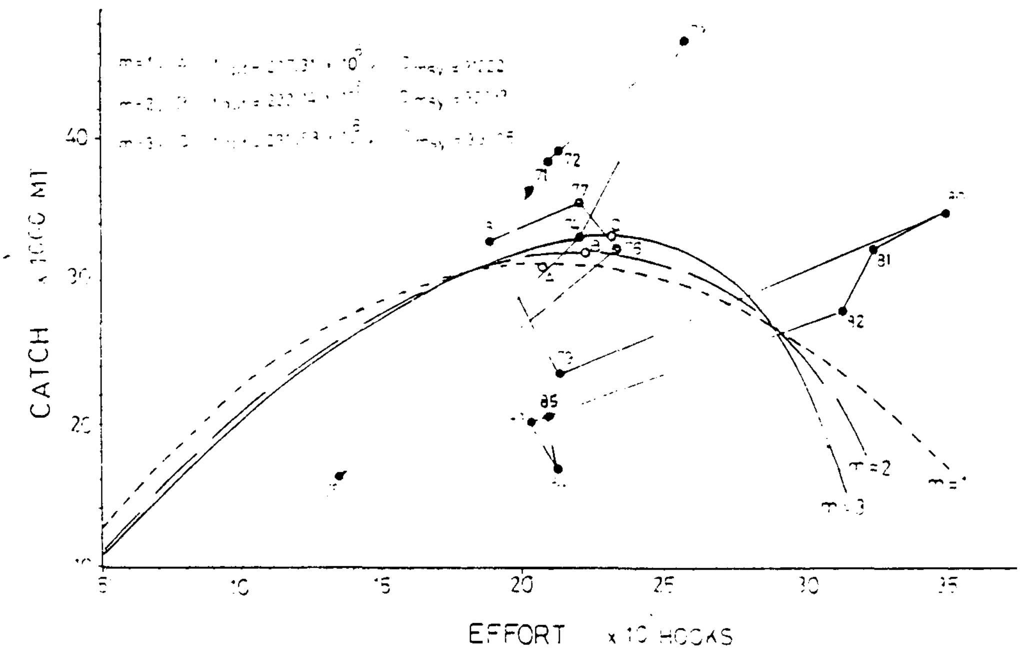

Fig. 4. Computation of optimal effective fishing effort and maximum sustainable yield of South Pacific albacore tuna longliners in the case of $k=5$.

$$f_{opt}=\left(\frac{a\,m}{b(m+1)}\right)\cdot 10^{9} \qquad C_{msy}=\left(\frac{a}{m+1}\right)\cdot f_{opt}\cdot 10^{-4}$$

DISCUSSION

Tuna longline fishery is very important in exploitation of tunalike fishes, especially in South Pacific albacore stock. Only three papers discussed the condition of the South Pacific albacore resource (Skillman 1975; Wetherall *et al.* 1979; Wetherall and Yong 1984).

The first comprehensive assessment was made by Skillman (1975). He estimated total catches based on the CPUE of American Samoan-based vessels and fitted to a production model. Based on catch statistic data in 1953-1972, he concluded that the South Pacific albacore fishery reached or nearly reached the level of MSY, giving the current constitution of the fishery. He also said that the stock was fully harvested, giving the prevailing practices, but left open the possibility that yield could be increased by altering the age-specific patterns of fishing mortality.

In Wetherall's report (1979), they estimated the annual Korean albacore catches based on catches of longliners of Taiwan and Japan. The analysis was based on catch statistic data of longliners in 1962-1977. The overall effective fishing effort on South Pacific albacore was estimated by dividing the composite index of abundance by the estimated total catch year by year.

The analysis was also repeated by Wetherall and Young (1984). They estimated the annual Korean albacore catches based on catches of longliners of Taiwan and Japan. Effective fishing effort on South Pacific albacore was estimated by dividing the composite index of abundance by the estimated total catch year by year. As pointed out by Wetherall and Yong (1987), their conclusions reveal that the average annual yield to longliners could not be increased by additional fishing effort, and in fact would be nearly as great with reduced effort. A cutback in effort would lead to lower costs per unit yield, and would provide a greater safety margin for the spawning stock. Their conclusions were essentially the same as those of Skillman's.

Wetherall and Yong (1987) calculated the abundance index which is defined as the albacore catch per day by Taiwanese longliners based at Pago Pago for the period 1976-1983 and the Japanese catch per day for 1960-1966, the latter figure adjusted for difference in the average fishing power between Taiwanese and Japanese longliners. As said by them, the index of abundance was a fairly crude estimation, ignoring variations in targeting, fleet distribution, gear configuration and other factors. And, the analysis was based on the catch data collected from the catch of longliners based at Pago Pago. They computed the total effective fishing effort by dividing these abundance indices by the total catch, and fittes to the surplus production model by an effective fishing effort of a 3-yr weight mean.

Although the production model can provide only a gross idea of how the longline yield responds to longline fishing effort, the complete and believable data are useful for giving more precise assessment of South Pacific albacore stock. In this paper, all of our computations are based on the official annual reports of catch statistics of longliners of Taiwan, Japan and Korea. The total catches of longliners of these three countries still account for well over 90% of the total catch from the South Pacific albacore stock. The overall effective fishing efforts are estimated by Honma's method for different data sources. Generally, Honma's method provides more suitable adjustment of effective fishing effort of tuna longliners. Hooking rates (catch per 100 hooks) are used to compute the index of abundance in this paper. And, only those comparatively believable data collected in 1971-1985, especially for Taiwanese and Korean, are used in this analysis.

In the future, how to standardize the effective fishing effort among these three longline countries will be an important problem in South Pacific albacore stock assessment. Moreover, we should consider that the rapid development of surface fishery in recent years could affect the recruitment of longliners.

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1971~1985 年間南太平洋長鰭鮪資源評估

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摘　要

以日本，韓國以及臺灣之鮪延繩釣漁業漁獲統計年報，估計 1971～1985 年間南太平洋長鰭鮪之漁獲量以及努力量。以剩餘生產量模式估計最大持續生產量時，以五年平均之努力量套算時，曲線之適合度最佳。就決定曲線之介值 $m=1\sim3$ 時，估算所得之最適漁獲努力量 f_{opt} 以及最大持續生產量 C_{msy} 分別如下。

$m=1$　$f_{opt}=207.31$ 百萬鈎，　$C_{msy}=31222$ 公噸

$m=2$　$f_{opt}=222.14$ 百萬鈎，　$C_{msy}=32033$ 公噸

$m=3$　$f_{opt}=231.58$ 百萬鈎，　$C_{msy}=33005$ 公噸